Research Policy 38 (2009) 26–34

Contents lists available at ScienceDirect

Research Policy

journal homepage: www.elsevier.com/locate/respol

Heterogeneity of patenting activity and its implications for scientific research

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ARTICLE INFO

Article history:
Received 30 April 2007
Received in revised form 23 June 2008
Accepted 3 October 2008
Available online 22 November 2008

PACS:
O31
O32
O34

Keywords:
Entrepreneurial universities
Academic inventors
Industry–science linkages
Patents
Technology transfer

ABSTRACT

The increasing commercialization of university discoveries has initiated a controversy on the impact for scientific research. It has been argued that an increasing orientation towards commercialization may have a negative impact on more fundamental research efforts in science. Several scholars have therefore analyzed the relationship between publication and patenting activity of university researchers, and most articles report positive correlations between patenting and publishing activities of scientists. However, previous studies do not account for heterogeneity of patenting activities. This paper explores the incidence of patenting and publishing of scientists distinguishing between corporate patents and patents assigned to non-profit organizations for a large sample of professors active in Germany. While patents assigned to non-profit organizations (incl. individual ownership of the professors themselves) complement publication quantity and quality, patents assigned to corporations are negatively related to quantity and quality of publication output.

1. Introduction

Academic researchers become increasingly active in commercializing their discoveries, which becomes impressively visible from the growing number of academic scientists among inventors on patents over the past decade (Henderson et al., 1998; Thursby and Thursby, 2002; Azoulay et al., 2006; Meyer et al., 2003; Lissoni et al., 2006, etc.). Many European governments actively promote commercialization activities of university scientists in order to enhance the usage of scientific research in industry through governmental funding programs. Often, such policy initiatives do not only encourage the commercialization of inventions through university spin-offs, but also industry–science collaborations. Despite some clear benefits of academy–industry collaboration and the involvement of scientists in commercialization activities, some analysts are rather sceptical about the implications for science, as commercialization goes hand in hand with securing property rights: does academic orientation towards commercialization reduce research efforts in the public domain as expressed by publication activity and its citation impact? Over the last years a fierce controversy emerged among policy makers and academics on the potential effects for the future of scientific research.

There is no doubt that close links between academia and industry have many positive aspects not only for the business partner (e.g. Zucker and Darby, 2000; Hall et al., 2001) but also for the academic sector, as for instance the realization of complementarities between applied and basic research (Azoulay et al., 2006), the generation of new research ideas (Rosenberg, 1998) and the overcoming of the “underfunding” of basic research through the private sector (Agrawal and Henderson, 2002). It is, however, unclear whether these benefits outweigh potential negative implications of a shift towards commercialization of science, which might be reflected in a decrease in the number and impact of scientific publications.

Given that scientists heavily depend on their academic reputation (Merton, 1968) a complete “crowding out” of scientific activities by commercialization endeavours is considered as highly unlikely (Azoulay et al., 2006; Thursby et al., 2005; Scotchmer, 2004). Scientific reputation is helpful – if not even necessary – for

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0048-7333/$ – see front matter
doi:10.1016/j.respol.2008.10.001

commercialization activities of scientists. Academic prestige and a strong position in the scientific community reduce uncertainties in the commercialization process and serves as a signal in the post-discovery period. It might play a crucial role in order to attract potential industrial collaboration partners and financiers or new scientific personnel. Recent empirical evidence broadly agrees on a positive relationship between patenting and publication outcomes of academic researchers for the US and many European countries (e.g. Agrawal and Henderson, 2002; Fabrizio and DiMinin, 2005; Stephan et al., 2007; Van Looy et al., 2006; Breschi et al., 2006; Czarnitzki et al., 2007). Some scholars argue that patents as commercialized discoveries are rather "by-products" of scientific work than substitutes (Murray, 2002).

Perhaps a more serious concern is that the quality of research might suffer from increased commercialization activities of scientists. Inventions demanded by the market do not necessarily touch academic research frontiers (Trajtenberg et al., 1997). Recent studies, however, argue that contacts to scientists in the business sector are enriching for university researchers (Agrawal and Henderson, 2002; Breschi et al., 2007) and that industry–science collaborations might even trigger new basic research (Rosenberg, 1998, for the US chemistry). Most empirical evidence supports a positive relationship of patenting activities and publication outcome as well as publication quality (e.g. Van Looy et al., 2006; Czarnitzki et al., 2007; Breschi et al., 2007; Azoulay et al., 2006, etc.). However, Azoulay et al. (2006) point out that they cannot rule out that patenting activities shift the scientist's interest towards research questions of commercial interest.

This study contributes to the debate on the patenting–publishing relationship by exploring the effect of heterogeneous patenting activities on the scientists' publication outcome and quality. Previous studies typically aggregate all patents produced by scientists abstracting from the fact that patents might be different (beyond the fact that they receive different numbers of citations as prior-art in future patents).[1] Therefore, we dig deeper into the patent–publication relationship than the existing literature by distinguishing between patents assigned to corporations and patents assigned to non-profit organizations, such as universities, private patents (owned by the scientist herself) and public (research) institutions. Based on a newly created large sample of German university professors, we established a link between the scientists' patent filings and their publication records. Our empirical study is based on a large sample of almost 3000 patenting professors holding about 7000 patents and having more than 34,000 publications in refereed journals. Our results contribute to the literature on the incidence of patenting and publishing of researchers by uncovering whether the often documented positive relationship between patenting and publication activities of scientists persists if heterogeneity in patenting is taken into account or whether this finding is driven by a subtype of patents taken out by the scientist. The results of our empirical analysis show that there are indeed differences: while patents in collaboration with non-profit organizations complement scientific publications, engagement in patenting with the business sector is associated with lower publication output and quality. The impact on quantity is weak, though.

The remainder of the paper is organized as follows: the next section summarizes existing evidence on the relationship between patenting and publishing; Section 3 describes the institutional background for academic patenting in Germany and shows some patenting trends of academic scientists in Germany over time; Section 4 explains the construction of the database; Section 5 shows the empirical analysis; Section 6 concludes.

2. Evidence on scientists' patenting and publication activities

The literature on the scientific performance of academics that are commercializing their scientific discoveries has its seeds in the fields of bibliometrics and technometrics. One major interest of this literature is to assess the co-development and convergence of science and technology. The 'science-intensity' of technology and other aspects of the science–technology relationship is often mapped by citation-based measures as non-patent references (NPRs) in patents (e.g., Narin and Noma, 1985; Cassiman et al., 2008) and patent references in scientific publications (e.g., Hicks, 2000; Glänzel and Meyer, 2003). The general conclusion from these bibliometric/technometric analyses is that in areas where science and technology have a common interface, science and technology are getting increasingly closer over time.

The strength of links established through publication citations in patents (and patent citations in scientific publications) is, however, somewhat limited. This is, among other factors, a consequence of the citation behaviour of authors, inventors and examiners as well as of the different functions citations have in scientific papers and in patent literature (Michel and Bettels, 2001).[2] Meyer (2006a) argues that citation linkages hardly present a direct link between cited paper and citing patent. Much stronger – and maybe even more meaningful – links are established trough collaborative knowledge production expressed by inventor–author relations as analyzed by Noyons et al. (1994) and Meyer (2006b). Meyer (2006b) focuses on patenting scientists active in nano-science and nano-technology. Based on a bibliometric analysis, he concludes that patenting scientists outperform their non-patenting colleagues in terms of publications and citations, on average. He concedes, however, that "co-active" scientists, i.e. scientists that engage in both publishing and patenting, do not have the lead in the top-performance class.

Bibliometric/technometric studies typically use qualitative and descriptive research methodologies, but several recent papers on the incidence of patenting and publishing employ econometric methods (e.g. Stephan et al., 2007; Azoulay et al., 2006; Fabrizio and DiMinin, 2005; Breschi et al., 2006; Czarnitzki et al., 2007). The major methodological advantage of those approaches is probably that individual-specific effects that are unobservable for the researcher can be taken into account, e.g. the scientists' ability to conduct research that has the potential to be published and their motivation (see Czarnitzki et al., 2007, for details).

Independent of the methodology used, recent studies broadly confirm the finding that science and technology are complementary. Stephan et al. (2007) investigate the correlation between publishing and patenting for a sample of Ph.D.s in the US. They find that the commercialization of discoveries is positively related to scientific output. Fabrizio and DiMinin (2005) use a matched sample of patenting and non-patenting US scientists to analyze their publishing performance. Based on fixed effects panel regressions they confirm a positive correlation. Breschi et al. (2006, 2007) provide evidence on the positive correlation between patenting and publishing for a matched sample of Italian scientists. Agrawal and Henderson (2002) depict the positive relationship for patenting and citation measures for researchers at the Departments of Mechanical and Electrical Engineering at the Massachusetts Institute of Technology. Azoulay et al. (2006) focus on university professors in the

[1] Exceptions are Breschi et al. (2006) and Fabrizio and DiMinin (2005).

[2] Agrawal and Henderson (2002) critically discuss the appropriateness of patent-based measures to evaluate public funding of university departments.

US. They find that patenting increases the number of publications, and that it has no impact on their quality. However, they cannot rule out that commercialization activities influence the content of the scientific research. Van Looy et al. (2006) find a positive correlation between patenting and publication activities for researchers at the Catholic University of Leuven. They further conclude that the journals in which academic patentees publish are not significantly more applied than those, to which their non-patenting colleagues contribute.

In summary, there is a well-documented positive correlation between patenting and publishing activities of academic scientists, and at least, there seems to be no negative effect of commercialization activities on publication quantity and quality, but maybe on the content. The previous literature does, however, mostly not distinguish between different types of patents.

So far, only Breschi et al. (2006, 2007) and Fabrizio and DiMinin (2005) pay attention to patent heterogeneity. Based on descriptive statistics for a sample of 299 Italian scientists Breschi et al. (2007) conclude that the correlation between patenting and publishing is strongest if patents are owned by business partners rather than by universities or the scientists themselves. They concede, however, that they have only a limited number of university patents in their sample. In consequence, they do not go beyond a descriptive analysis of patent heterogeneity. Breschi et al. (2006) find a similar link for a larger sample of patenting scientists identified by the EP-INV database (described in Balconi et al., 2004). In this paper they find that collaborations with co-authors in business are positively related to the publication output of university scientists. Fabrizio and DiMinin (2005) distinguish between patents assigned to university and corporate patents and investigate their impact on publication outcome for US scientists. Due to the fact that in the US the university owns inventions made by the employed scientists (see Section 3) patents assigned to universities account for 76% of their sample. Fabrizio and DiMinin (2005) find that university patents complement publications, whereas there is no significant impact of corporate patents. They do not provide evidence on the impact of patent heterogeneity on publication quality. Investigating the determinants of ownership of the US patents taken out by university scientists Thursby et al. (2007) explore the fact that one fourth of US patents are solely owned by firms. For the US, where inventions produced at universities belong to the university by law, the share of university discoveries, which is not patented by universities, seem rather high. From interviews with university and industry personnel, Thursby et al. (2007) conclude that the majority of those patents can be seen as the result of faculty consulting. They can, however, not rule out that part of those patents is such that rightfully belong to the university. Another result they present is that patents assigned to universities are more basic than patents assigned to universities.

This paper contributes to the existing literature by exploring a potential difference between different ownership of patents, i.e. corporations vs. research institutions, and whether this difference becomes visible in publication count and citation impact of patenting scientists.

3. Academic patenting in Germany and patenting trends for German scientists

3.1. Academic patenting in Germany

Most empirical studies investigating patenting activities of university scientists focus on the US. The bone of contention was the US Bayh-Dole Act in 1980 (and its amendment in 1984 and its augmentation in 1986) that, among other issues, strengthened the universities' patenting rights and encouraged patenting activities of university scientists. A couple of papers evaluate this change in law to find out whether the presumed positive effects on technological progress through increased commercialization of university inventions actually took place or whether it just led to increased patenting of marginal inventions by university scientists. Empirical research finds that university patents were more important than corporate patents in the pre-Bayh-Dole period in terms of citations they received by future patents (Henderson et al., 1998; Sampat et al., 2003; Rosell and Agrawal, 2006). Bayh-Dole has not changed this fact (Sampat et al., 2003). Potential negative effects on patent quality are rather found to be driven by inexperienced universities that started patenting after Bayh-Dole (Mowery and Ziedonis, 2002). Those effects are found to disappear after some experience could be gathered (Mowery et al., 2002).

Unlike in the US, there exists no common legislation on university patenting in Europe. In the recent past, however, university patents experienced quite some attention in Europe and many countries provoked important changes in law—although in different directions. Whereas Germany recently made a comparable step to Bayh-Dole through the abolishment of the so-called professors' privilege in 2002, Italy, for example, has introduced a professors' privilege in the same year. In other European countries like the UK each university has its own rules with regard to the ownership of inventions made at universities. Verspagen (2006) and Geuna and Nesta (2006) provide surveys on the status quo and recent developments in Europe.

Germany had its Bayh-Dole Act quite late as compared to the US. Once derived from Article 5 of the German constitution, which pertained to the freedom of science and research, the professors' privilege was an exception from the law that declared that professors were the only occupational group in Germany that had the right to claim ownership of the results of their scientific work, even if the underlying research was financed by the university. In February 2002, the professor's privilege was abandoned because it was suspected to inhibit science and technology transfer from science to industry (Kilger and Bartenbach, 2002).

Under the professors' privilege, professors had not only the freedom to commercialize their inventions. They also had to deal with the administration tasks associated with commercializing their discoveries and they bore all financial risks of filing a patent application including application fees and potential infringement costs. As the distribution of the value of patents is very skew (Harhoff et al., 1999) university professors faced the risk that the costs of patenting could exceed the expected profits, which reduced their incentives to patent their inventions. After the change in law, when universities were declared the ownership of inventions made inhouse they also took over financial risks and organization efforts of the patenting procedure. The professor receives 30% of the revenues from exploiting his invention through the university (Kilger and Bartenbach, 2002).

Although the rights of German universities were significantly strengthened through the abolishment of the professors' privilege (comparable to the implications of Bayh-Dole for US universities), the change in law also implied some challenges. Unlike the large US universities (Siegel et al., 2003) and exceptionally few European universities, most German universities did not maintain professional technology transfer offices (TTO) that assisted scientists in commercialization.[3] German universities only recently

[3] Debackere and Veugelers (2005) studied one exceptional case, the TTO of the Catholic University of Leuven in Belgium, which is a good-practice example of professional management of technology transfer from science to industry. This case may serve as role-model for other universities in Europe. In Germany, the Federal Ministry for Education and Research launched a large study on technology transfer

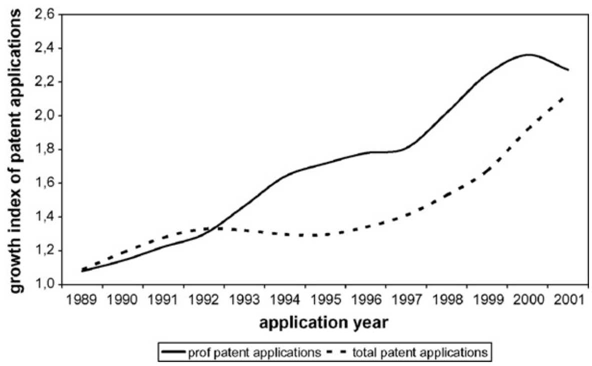

Fig. 1. Three-year moving average of the patents filed by German professors.

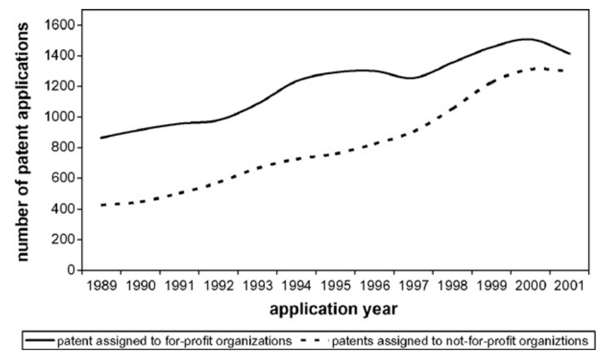

Fig. 2. Three-year moving averages of the distribution of professors' patents by type of assignee.

started developing more professional organizational structures to support commercialization of university discoveries. Beforehand technology transfer took place, but was largely based on bilateral relationships of selected professors and the business sector.

3.2. Patenting trends for scientists located in Germany

After having presented a brief overview on the conditions for patent activity of professors in Germany, this subsection presents some descriptive evidence on their patenting activities in recent years. Due to the presence of the professors' privilege until 2002, we focus our study on the time before the policy change.[4] Given that, 'professor patents' are defined as patents with at least one professor on its inventor list in the period from 1989 to 2001 (see Section 4 for details). We cannot rely on assigneeship of universities, as this would be only exceptional cases given the legislation. Typically, universities would not appear as assignee but the individual professors or corporations/institutions with whom the academics collaborated. We focus on patents applied for at the German Patent and Trade Mark Office (DPMA) and at the European Patent Office (EPO) as most of the patents developed in Germany are registered with either one or both of these patent offices.

Fig. 1 shows the development (growth index) of professor patents over time as compared to the total patent applications by German inventors. There is a strong increase in both types of patens during the 1990s. Patent applications by university professors increased by 105% over the period 1987–2001. At the peak in 2000, the growth from 1987 reached 121%.

A look at the distribution of patents filed by professors according to their assignees (see Fig. 2) shows that most patents are filed in collaboration with companies (for-profit organizations). Patents assigned to universities, other non-profit research institutions and privately owned patents by the professors occur less frequently. The fact that the professors' privilege was in place until recently explains that most inventions made at German universities are not assigned to universities. This is in contrast to the US where the majority of university inventions (about 75%) is patented through to universities (Fabrizio and DiMinin, 2005; Thursby et al., 2007). Corporate patents of professors can reflect their consulting activities (Thursby et al., 2007), but they can also indicate that German professors avoid the risks and efforts of patenting themselves and therefore search to collaborate with firms in order to patent their inventions. Fig. 2 further shows a surge in non-profit patents, which exceeds the increase in corporate patents over time. In 2001, there are only about 200 patents less assigned to for-profit organizations than there are for non-profit organizations.

4. Data sources

4.1. Construction of the sample

The empirical analysis of this study is based on a newly created data set that contains patent applications and publication records for university professors active in Germany. The starting point was the database of the German Patent and Trademark Office (DPMA) which contains all patents filed with the DPMA or the European Patent Office (EPO) that protect an invention in Germany. We have access to patent filings from 1980 onwards. Patent applicants at the DPMA and the EPO must designate the inventor of the patent. Otherwise the patent application will be deemed withdrawn. We used the inventor information to identify all inventors based on the persons' title "Prof. Dr." and variations of that. The professor title is protected by the German criminal code (article 132a) against misuse by unauthorized persons. In Germany, the award of a doctorate and even more of a professor title is considered a great honour. Accordingly this title is used as a name affix not only in academic environment, but also in daily life. We checked whether the names of our identified professors appeared in the patent database without the title but with the same address in order to verify that the professor title field is always filled in the data. The verification of a sample of persons had shown that we can identify university professors (or professors at other higher education facilities such as polytechnical colleges) by their title with high precision. It basically never happens that inventor names appear sometimes with "Prof. Dr." (or similar title) and sometimes without on other patents. Thus, we can safely argue that with focus on Germany this procedure delivers a listing of patents where professors are recorded as inventors. In total, we found 42,065 inventor records with professors. As there are sometimes multiple professors listed as inventors on one patent, the number of different patents with professors among the inventors amounts to 36,223.

As the inventors had to be linked to publication data, we first had to identify a list of unique inventors from the identified patents, that is, we had to create a key that identifies the same person on multiple patents. This was conducted by both computer assisted text field searches and manual checks. First, we used a text field search engine on name and city of residence of the inventors (by putting a high weight on name similarity). The potential matches of identical

in Germany in 1998/1999. Among other issues, the report found that most university TTOs have many tasks, but that they are largely understaffed to fulfill these in a professional manner. Most TTOs are only run by a single person or even on part-time basis (50% of a full-time equivalent person). See Schmoch et al. (2000) for the detailed report.

[4] While it would be highly interesting to study the effects of the abolishment of the professors' privilege, we do not have sufficient data available yet. Currently, our data ends in 2002, and it would be desirable to have 4–6 years after the policy change to evaluate its short-term and medium-term impacts, at least.

person records on different patents were manually checked afterwards. If the text fields of last name and first name or initials and city were sufficiently similar we assigned "hits". In case the city was different, we cross-referenced with other information if the person is identical, that is, field of research, distance among cities and distinctness of names, and Internet searches. This approach allows tracing professors who move during the observed period. Of course, there were occurrences where it was not possible to code records as identical persons. If very common names like "Müller" or "Schmidt" appeared with common first names and large or different cities we preferred to drop such inventors from the lists to avoid erroneous assignment by not solvable homonyms. In total, we discarded 6758 out of 36,223 patents, where we were not able to create a unique person ID. The remaining 29,465 patents turn out to contain 6324 different professors. The sample is still representative of the population of patenting professors, as the homonym problem should not bias the results of the empirical analysis. Names should not be correlated with other personal characteristics, such as abilities or attitude towards commercialization.

In the next step, we coded the assignees of the patents with professors as inventors into two groups: assignee is

1. a for-profit entity (corporations);[5]
2. the professor herself, a university or another non-profit entity.[6]

This grouping serves as the criterion to distinguish the different patent types in the upcoming empirical analysis.

The professors who were listed as inventors on the patents were traced in the Web of Science® database of Thomson-Scientific (Philadelphia, PA, USA). We used a similar search algorithm as described above, but the fact that the patent data contain the place of residence of the inventors while the bibliographic database records the authors' institutional address made additional manual cross-referencing necessary. The high amount of required manual checking of records forced us to restrict our further analysis on the linked data to a 5-year period from 1997 to 2001 leaving us with 10,431 different patents with 2936 different identified professors as inventors. In total, we matched 40,527 publications to the inventors for this 5-year period.

As we will use fixed-effects panel regressions (as described below) in our empirical analysis, we can only use professors that have at least one publication in our time window.[7] After some outliers were removed, we end up with 9300 observations corresponding to 1876 different professors. In total, these professors applied for 7070 patents and have 34,584 publications in ISI journals.

5. Empirical analysis

5.1. Descriptive statistics

This section introduces our sample with some descriptive statistics. Table 1 presents the means, standard deviations as well as minima and maxima of the variables used in the subsequent regression analysis. The unit of analysis is the professor per year. In order to measure publication activity we use three different measures for publication outcome and quality:

Table 1
Descriptive statistics of variables used in the regression analysis.

	# observations = 9300			
	Mean	Std. Dev.	Min.	Max.
Publication data				
# publications	3.71	4.73	0	24
# weighted publications	17.93	30.98	0	347.76
# citations[a]	22.77	45.63	0	708
Patent data				
Non-profit patents	0.35	1.09	0	20
For-profit patents	0.41	1.43	0	29
Controls				
Experience	2.65	4.33	0	16
Total number of publication in main science field per year	10011.42	3773.83	2454	14,474

Time dummies not presented.
[a] The citation data stems from a reduced sample of 8430 observations, as some professors received zero citations over the whole 5-year period. Consequently, these will be dropped from the fixed-effect regressions on citations.

- The first measure is a simple count of publications per researcher per year. On average, each professor in our sample has 3.71 scientific publications per year. Note that the main fields of publication activity are chemistry and physics. More than 20% of the total publications are attributable to either one of the fields. More than 10% of the publications belong to the clinical and experimental medicine and the bioscience sector. The fields will not be used explicitly in the empirical analysis, however, as such time-constant effects are absorbed by individuals' fixed effects that we will employ in the regressions.
- Our second publication outcome measure is the publication count per year weighted by the journal impact factor (JIF) to account for the quality of academic publications.
- As a third measure, we use the citations made to the professors' academic publications as an indicator of the articles' individual quality and not journal quality as in the JIF-weighted number of publications. The citation window is equivalent to the one that is used for the Web of Science's official journal impact factor, i.e. we counted all citations received in subsequent 3 years after the publications. Although citations are not immediately an indication of research quality, Holmes and Oppenheim (2001) have shown that citation measures significantly correlate with other quality measures. The average professor in Germany receives about 23 citations to her published work in a 3-year window.

The regressors of main interest address patent heterogeneity. The first variable is the number of patents the professor filed with a firm assignee per year; the second variable stands for her patent applications with non-profit organizations per year. On average, a professor files 0.35 patents with a non-profit assignee, and 0.41 patents with a corporation per year.

Besides our variables of main interest we use the number of scientific publications in the main science field of the professor's activity to account for variation in the publication pattern across science fields. An increase in publications in a particular science field is likely to impact the publication activity and the citations received by professors which are active in this field. Note that the inclusion of field dummies is not necessary, as heterogeneity across fields is captured by the fixed effect in the regressions. To account for skewness we use the logarithm of this variable in the regression

[5] There was a handful of patents that were co-assigned to corporations and non-profit entities. In that case, we used fractional counts.

[6] Such institutions include the major public non-university research institutions in Germany (Max-Planck Gesellschaft, Fraunhofer Gesellschaft, Helmholtz Gemeinschaft, and others), but also associations, foundations and other non-commercial entities including the government.

[7] Individuals without publications, i.e. the value of the dependent variable is equal to zero in all time periods, would not contribute to any coefficient estimate, as a time-constant dependent variable would be completely absorbed in the fixed-effect (being equal to zero).

model. Further, we lag this variable by 1 year to avoid endogeneity.

Finally, we use the experience of a professor. The more experience a professor has towards commercialization activity, the less it may distract him from publication activity. Therefore, we use the time elapsed since their first patent application as a measure of such experience, and also include its squared term in the regressions as the effect may be non-linear (see the literature on academic life cycles, e.g. Diamond, 1986; Levin and Stephan, 1991; Turner and Mairesse, forthcoming; Hall et al., 2007; Lowe and Gonzalez-Brambila, 2007). As already described in Fig. 2, there is a strong increase in professors entering the patent system as inventors. Whereas the percentage of scientists that belong to the cohort that started patenting before 1986 is small with 9%, 19% enter between 1987 and 1992, followed by a further increase to 33% of professors entering between 1993 and 1998. 39% of the professors had their first patent between 1998 and 2001.

In addition to the information presented in Table 1, it is noteworthy that 97% of the patenting professors in our sample are male. Only 2% of patents correspond to female scientists.[8]

5.2. Panel data regression

To further explore the publication–patenting relationship with respect to heterogeneity in patenting, we perform count data panel regressions. We employ fixed-effects Poisson models as introduced by Hausman et al. (1984). As the basic Poisson model assumes equi-dispersion, i.e. the equality of the conditional mean and the variance, scholars have used negative binomial regression models in the past decades, as these allow for over-dispersion, which is typically present in microdata. Over-dispersion refers to the phenomenon that the variance is larger than the conditional mean. However, as Wooldridge (1999) has shown, the Poisson model is still consistent in case of over-dispersion. However, the standard errors are biased and thus have to be corrected, which amounts to the calculation of fully robust standard errors. Compared to the Negative Binomial models, this has the advantage that one does not have to make an assumption on the functional form of the variance term, as it may lead to inconsistent estimates if this assumption fails.[9]

While the publication and citation counts are real counts, i.e. the values of the dependent variables are non-negative integers, the journal impact factor-weighted publication counts are not strictly count data, as the values are not necessarily integers. However, as Wooldridge (2002, p. 676) points out, the fixed effects Poisson estimator works whenever the conditional mean is correctly specified. Thus, even if the dependent variable is not an actual count, but a non-negative continuous variable, the estimator still has all desirable properties of the actual count data model. Therefore, we also apply the same model to the non-negative continuous variable of publication counts that are weighted by the journal impact factors.

Having defined our variables and chosen an empirical approach our specification looks as follows:

$$E(y_{\text{it}}|x_{\text{it}}, \alpha_i) = \alpha_i \ \exp\left(x'_{\text{it}}\beta\right), \qquad (1)$$

where α_i denotes the individual-specific effect. Hence, Eq. (1) disentangles the influence of patenting (which is included in the vector of covariates) and unobserved specific skills of each researcher causing heterogeneity in average publication activity over the cross-section of scientists in the sample. Note that individual specific attributes of the professor, such as gender, are not included in the specification. Those are absorbed by the individual-specific effect as they do not change over time.

The patent variables are timed by application year, and are included as a 1-year lag in the regressions. As we intend to analyze whether commercialization activity is correlated with scientific publication output, it is desirable to contrast publication and patent activity that took place at the same time, that is, the time window when the scientist was most probably using his or her time for both activities in parallel. We observe the application date in the patent database, and thus we can assume that the researcher had worked on the underlying technology closely before filing the patent application. For the publications, however, we do not observe journal submission date but only publication year. The submission must necessarily have taken place a certain time before publication. In absence of a better guess, we model that the researchers submitted their papers about 1 year before the publication of the article in a journal. By using a "publication in period t" to "patent application in $t-1$" relationship we attempt to approximate a time window where the scientist worked on both the publications that appeared in year t and patents filed in $t-1$, such that the actual research for publishing and patenting took possibly place in year $t-2$. Of course, we are aware that publication lags may vary in time, but currently we do not have any better information at hand, which would improve the selection of a more appropriate time window.[10]

Table 2 presents the estimation results. The first column presents the results for the estimation for the publication outcome as measured by the number of publications per year. The second column shows the estimated coefficients for the journal-impact factor weighted publication outcome of the professors, i.e. quality-adjusted publication counts, and the last column the estimation for the citations received per year. In addition to the standard errors of the "traditional" fixed effects Poisson model, Table 2 presents adjusted standard errors following Wooldridge (1999), which are consistent also in the case of over-dispersion whereas the former are not.

The results show that the number of non-profit patents increases publication quantity and quality. The finding holds if publications are weighted by journal impact factor. Hence, with respect to non-profit patents we can confirm a positive patent–publication relationship as was found by previous studies (Murray, 2002; Stephan et al., 2007; Fabrizio and DiMinin, 2005; Azoulay et al., 2006; Breschi et al., 2006; Czarnitzki et al., 2007). If quality is measured by received citations, the coefficient is still positive, but is significant only at the 10% level when robust standard errors are applied.

With respect to corporate patents the result is not in line with a positive patent–publication relationship. We find that scientists' engagement in corporate patents has a negative, although statistically only weakly significant, effect on publication quantity. Further, we find that for-profit patents negatively correlate with the quality of publications as measured by citations. This negative relationship already appears in the regression on the journal impact factor-weighted publications, which does not hold if robust standard errors are used, though.

In order to interpret the magnitude of the findings, we calculated several marginal effects. First, we focus on the negative impact of for-profit patents. Since the effect on publication counts

[8] 1% of the inventors in our sample could not be classified with respect to gender because their patent records contained initials only or because the first name was foreign and we were not able to determine whether it refers to a male or female.

[9] All regressions were carried out in STATA using the quasi maximum likelihood conditional Poisson fixed effects model with fully robust standard errors by Tim Simcoe, University of Toronto.

[10] We also experimented with other lag structures including contemporaneous relationships and interactions of patents and time dummies in our regression analysis, but that did not improve the results.

Table 2
Conditional fixed-effects panel regressions.

Dependent variables Covariates	Number of publications$_{it}$ Coefficient (std. err.) (robust std. err.)	Impact-factor weighted number of publication$_{it}$ Coefficient (std. err.) (robust std. err.)	Number of citations$_{it}$ Coefficient (std. err.) (robust std. err.)
# Non-profit patents$_{i,t-1}$	0.012 (0.004)*** (0.005)**	0.017 (0.002)*** (0.006)***	0.018 (0.002)*** (0.010)*
# For-profit patents $_{i,t-1}$	−0.006 (0.004)* (0.003)*	−0.006 (0.002)*** (0.005)	−0.018 (0.002)*** (0.007)***
Log(# publ. in main science field $_{i,t-1}$)	1.439 (0.191)*** (0.277)***	1.172 (0.092)*** (0.337)***	1.242 (0.086)*** (0.489)***
Experience$_{it}$	0.269 (0.009)*** (0.012)***	0.213 (0.004)*** (0.016)***	0.216 (0.004)*** (0.216)***
(Experience$_{it}$)^2/100	−0.806 (0.056)*** (0.082)***	−0.706 (0.026)*** (0.098)***	−0.712 (0.025)*** (0.146)***
1998	0.476 (0.022)*** (0.033)***	0.313 (0.010)*** (0.039)***	0.288 (0.009)*** (0.062)***
1999	0.387 (0.021)*** (0.028)***	0.228 (0.009)*** (0.035)***	0.205 (0.009)*** (0.054)***
2000	0.291 (0.019)*** (0.024)***	0.185 (0.009)*** (0.031)***	0.183 (0.008)*** (0.048)***
2001	0.087 (0.019)*** (0.022)***	0.038 (0.009)*** (0.028)	0.043 (0.008)*** (0.046)
Number of observations	9300	9300	8430[a]
Wald-X^2	1126.78***	2994.44***	3483.08***
Wald-X^2 for robust model	596.62***	224.37***	115.24***

[a] Our sample for the citations received is smaller because we cannot use observations corresponding to professors that did not receive any citation in our observation period.
* Correspond to a 10% level of statistical significance.
** Correspond to a 5% level of statistical significance.
*** Correspond to a 1% level of statistical significance.

is only weakly significant, we discuss the impact on publication quality measured as received citations. The marginal effects of the for-profit patents amounts to a reduction of quality of 2%. This corresponds to 0.4 less citations to publications at the average of the patent variable. Note, however, that average interpretation may be misleading in nonlinear models. As the citation variable is highly skewed, we also considered the effect at the median. Then the 0.4 reduction in received citations reflects a 13% decrease in quality.

Second, non-for-profit patents have the following effect on publication quality as measured by citations: the marginal effects also amounts to about 2%, which reflects 0.4 more citations, on average, and also a 13% increase at the median value. Now suppose, two professors with same abilities decided to commercialize. One, however, engages in a research project where the university takes out the patent, and the other collaborates with industry. All else constant, the industry-engaged researcher would suffer from a 26% quality gap.

The further covariates show that, not surprisingly, more publication output in the field of science of a professor also results in more publication for each individual, but also higher quality in terms of impact factors of journals and citations received. The experience measures are highly significant in all regressions, and reveal an inverse u-shaped relationship as it has been commonly identified in the literature on academics' life cycle productivity. Note, however, that the extreme value of the u-shape is basically at the right edge of the experience distribution in our sample. Thus, patenting experience generally leads to less distraction from publication activities, the more experience a professor has.

There are several reasons for a positive relationship between patenting and publishing. Possible explanation range from the importance of an academic reputation to attract industry collaborators that support commercialization of university inventions (Azoulay et al., 2006) to the emergence of university patents as a by-product of scientific work (Murray, 2002). Little effort has been paid so far to heterogeneity of patenting activities of university professors. The contribution of our paper is to investigate whether this incidence of a positive correlation between patenting and publishing activities of scientists hinges on a specific type of patents. Distinguishing between patents assigned to non-profit organizations and patents assigned to corporations our empirical analysis shows that the positive patenting–publishing relationship indeed does not hold for all types of patents taken out by university scientists. Whereas university patents, patents owned by non-profit organizations and private patents of the professors complement their research activities in terms of publication outcome and quality, this is not the case for professor patents in collaboration with the business sector.

The finding that corporate patents do not complement publication quantity is in line with the conclusion of Fabrizio and DiMinin (2005) from their analysis of publishing and patenting activities of a sample of US scientists. Fabrizio and DiMinin (2005) argue that corporate patents do not support scientific publications as do university patents because patents in collaboration with the business sector may deviate from traditional academic science and hence may rather be associated with more of a drain on the researchers' time. Hence, they conclude that such activities are likely to substitute part of the time deviated to academic research.

With respect to publication quality we find such a negative correlation with corporate patents. Hence, one could argue that the drain of scientists' time becomes apparent in terms of the quality of their publications. Corporate patents might not necessarily touch academic frontiers. Hence, there is a high chance that activities related to these projects do not lead to high quality publications. This is in line with the argument of Trajtenberg et al. (1997) that corporate patents differ from university patents in that they are rather applied in terms of technology content, or have possibly more incremental nature.

Table 3
Bivariate correlations.

	Variable	Correlation coefficient (significance level)					
		(1)	(2)	(3)[a]	(4)	(5)	(6)
(1)	# publications$_t$	1.00					
(2)	# JIF-weighted number of publications$_t$	0.81	1.00				
(3)[a]	# citations$_t$	0.69	0.86	1.00			
(4)	# non-profit patents$_{t-1}$	0.07	0.04	0.04	1.00		
(5)	# for-profit patents$_{t-1}$	0.07	0.05	0.03	−0.01	1.00	
(6)	Log(# publ. in main science field$_{t-1}$)	0.14	0.03	0.02	0.03	0.03	1.00
(7)	Experience	0.20	0.11	0.06	0.04	0.19	0.06

[a] The correlation table is based on our sample of 9300 observations, except for citations. As not all professors receive citations (column 3) the relevant sample size of 8340 observations is used for these figures.

6. Conclusions

The increased engagement of university scientists in commercializing their discoveries over the past decades led to a discussion on potentially negative consequences for future science. Policy makers and analysts fear that significant commercialization activities of scientists may replace part of their research activities and also lead to a reduction in research quality. Empirical evidence for the US and European countries shows, however, that scientists do not publish less than other researchers if they engage in patenting. Scientists that do both publishing and patenting are rather found to be "stars" that outperform their non-patenting colleagues in terms of publication outcome and quality.

As we have shown, not all patents of professors have the same impact on publication activities. Among all patents that have a professor listed as inventor, we distinguish between non-profit patents (i.e. patents assigned to professors, their universities, or non-profit research institutions), and patents assigned to corporations and explore whether the positive relationship of patenting and publication activities of professors hinges on a particular type of patents.

Our results are based on a large database of German scientists that are active in patenting. In earlier work with this data, we confirmed previous international findings in the sense that we also find a positive relationship between patenting and publication quantity and quality for German professors in Czarnitzki et al. (2007). However, this paper shows that heterogeneity in patenting matters. Patenting with non-profit organizations does not reduce publication output, but instead increases publication quantity and quality. However, patents assigned to corporations have a negative impact on publication quantity and quality. The positive result for patents with non-profit organizations is probably explained as the research projects are likely to be closer related to fundamental research than projects with business partners. To conclude, our finding suggests that patents are not necessarily by-products of scientific publications and that the overall positive effect of patenting and publication activities of professors is likely to be driven by a specific type of patents.

Our analysis is not without limitations. We cannot claim that the identified relationships between patent and publication measures are strictly causal. Rather we just identify multivariate correlations. In order to infer causality we would have to find instrumental variables that relate to patenting but are not influenced by publishing. Given the limitations of our data at this point, we have no convincing candidates for such instruments at hand. It would, for instance, require collecting additional variables on the professors personal characteristics and their faculty environment which is difficult as no systematic databases exist.

As an interesting path for further research on German institutional circumstances, we suggest to further investigate the collaborations of German professors with non-profit institutions. It may be interesting to construct structural variables describing the technology transfer capabilities which are present at the professor's institutions and their patent collaboration partners in the non-profit sector to estimate the surplus of well managed technology transfer institutions, or, possibly more interesting, the forgone benefit implied by the non-existence or low functionality of such transfer establishments. Therefore it would be interesting to compare universities with institutions such as the Max-Planck Society, the Fraunhofer Society and the Helmholtz Society.

Finally, it should be noted that the negative impact of engagement in corporate patenting does not necessarily challenge the increased orientation towards commercialization in academia. It may well result in a positive net-effect from a macroeconomic point of view, at least in short to medium term view. To find an ultimate answer, one would have to contrast the economic loss of lower publication activity with possibly higher returns and growth in the business sector that may have been achieved through collaboration with academia in form of patent filings and thus intellectual property.

Acknowledgements

We thank three anonymous referees, the editor, and the participants of the Annual Conference 2007 of the Technology Transfer Society held at Palm Desert, CA, and of the 34th Annual Meeting of the European Association for Research in Industrial Economics (EARIE) held at Valencia. Katrin Hussinger gratefully acknowledges financial support under the grant KUL-OT/04/07A.

Appendix A

Table 3.

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